Muon Lifetime Experiments

Overview: Yesterday afternoon, Glen spoke about relativistic time dilation. He explained how time passes more slowly in reference frames that move close to the speed of light. Over the next couple days we can do experiments with cosmic ray muons to actually show this happening.

We will do two experiments. The first will measure the half-life of muons that are moving close to the speed of light. The second experiment will measure the half-life of muons that are at rest. If these half-lives are different, then we will have direct evidence of Einstein's theory of relativity!

Large Group Discussion Questions:

1) What are some reasons that you might expect to count fewer muons/minute at the bottom of Mt. Diablo than at the top?

2) If muons have a particular half-life shouldn't all of them decay at the same point: either before they reach the top of the mountain, in between top and bottom, or after they reach the bottom?

Small Group Discussion Questions

3) If the muons/minute at the bottom of the mountain is only a little smaller than the muons/minute at the top, what does this tell you about the 1/2-life? (short or long) If the muons/minute are very different at top and bottom, what does this tell you (short or long 1/2-life)? Explain.

4) Roughly speaking, how fast are cosmic ray muons moving? About how long will it take for a muon to go from the top of Mt. Diablo to the bottom? Top elevation: 3849 ft.; bottom elevation: 0 ft.

5) You have probably studied exponential growth and decay in a math class. You may have solved problems involving compounding interest, population growth, or radioactive half-life. Formulas for these all look about the same. For example:

Present Value = Pe^{rt} where P is the principle, r is the interest rate, and t is the time that it is invested

$y = P_0e^{kt}$ where P_0 is the initial population size and y is the later population size, and k is the growth rate

$N = N_0e^{-kt}$ where N_0 is the initial number of atoms in a substance, N is the number of atoms remaining after time, t, and k is the decay constant. "k" is related to the half life, $t_{1/2}$ by: $\frac{1}{2} = e^{-k(t_{1/2})}$ This is just the same equation where $N = \frac{N_0}{2}$.

So... suppose we measure 150 muons/minute at the top of Mt. Diablo and 100 muons/minute at bottom. What is the 1/2-life of the muons?

If you have extra time, ponder these:

6) Nowhere in our calculation did we account for the time that muons spend traveling from high in the atmosphere to the top of Mt. Diablo. Should we account for this? If so, how? If not, why not?

7) In our 1/2-life calculation we assumed that the difference in muons/minute was due only to muons decaying on the way down. If some muons actually get slowed down and stopped by collisions with air molecules, would your 1/2-life calculation be an overestimate or an underestimate?